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# Multinomial Lattice Method to Determine Stock Prices on Blockchain

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***Abstract***

*This research investigates the integration of the multinomial lattice method with blockchain technology to enhance the determination of stock prices, particularly for European-type Asian options, aiming to improve market transparency, security, and efficiency. The study employs a documentary research approach, reviewing existing literature on the multinomial lattice method and blockchain technology. The researcher organizes and interprets findings to provide a comprehensive summary. The application of the multinomial lattice method allows for the calculation of Asian call option prices by considering key parameters such as the strike price, interest rate, and share value. Implementing this method on the blockchain facilitates decentralized management of stock option contracts, enhancing transparency and security in price determination. The research relies on existing literature and lacks empirical data to validate the findings. Future studies could explore real-world applications and effectiveness in various market conditions. The findings suggest that combining these technologies can improve corporate governance and stakeholder trust in financial markets. The research relies on existing literature and lacks empirical data to validate the findings. Future studies could explore real-world applications and effectiveness in various market conditions.*

***Keywords:*** *Multinomial Lattice, Stock Prices, Blockchain Technology, Network Security*

## Introduction

As the world of investment develops, various types of assets are typically traded. They can be used as alternatives, such as company shares, foreign exchange rates, or loan contracts with various interest variations and others. Apart from that, there is also a popularly traded financial object called "financial derivatives." These derivatives are highly traded considered profitable for investors. Many financial instruments can be categorized as derivatives, but options/futures contracts are the most commonly known. Options/futures contracts give the holder the right to sell/buy an asset at a predetermined price and time. Options are divided into two types, namely call options (buy) and put options (sell). Apart from that, options are also divided into two other types, namely vanilla options, which are based on the use of time.

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These include European options, which can only be exercised at maturity; Americans, which can be exercised at any time until a predetermined time limit; and exotic options, which are the only example of an Asian option. Asian options are popular with many because they eliminate the possibility of option holders being cheated by manipulating asset prices at the final moments before maturity. There are two ways to determine the price of an Asian call option: derived analytically or approximated numerically. One numerical method that can be used is the lattice multinomial. This method is a development of the lattice binomial method and has a higher accuracy value than the lattice binomial method because it uses more nodes. Several studies have been conducted regarding the issue of Asian options and the lattice method to assist in determining option prices. The multinomial lattice method can be used to calculate European-type Asian options using a lattice binomial scheme, and the higher the strike price value, the smaller the resulting option price, while the higher the interest rate value, the smaller the resulting option price.

So, it can be concluded that the multinomial lattice method can be used to calculate European-type Asian options. Determining Asian option prices can be done using the arithmetic average or geometric average(Fitriyana et al., 2015). Apart from that, there are several models and methods for determining Asian option prices, including the Black-Scholes model, which is very accurate and allows for quick calculation of option prices. However, this model does not consider the impact of dividends paid during the option period. The lattice binomial method is one in which each step predicts two possible stock prices, namely rising and falling. However, this method is complicated to build and depends on the number of steps used (Stringham, 2015).A blockchain is a distributed ledger technology comprising transactional data recorded on interconnected blocks that are linked to a chronological chain. Blocks can form and connect in any way imaginable, as long as a transaction chronology is established.

However, the formation of blocks into chains has become widely popularized. A chain is a series of individual links aggregated to form a unitary succession, and when the chain is made taut, the succession becomes horizontal. A chronology shown horizontally is common because the starting and end points are depicted clearly when portrayed linearly. When blocks interlink and form a chain, the starting point (the genesis block) represents past transactions, and the endpoint represents the transactions that occurred most recently. Each newly formed block only interlinks with the one preceding it in the chain.The linear makeup of block production has not caused what is known as the Blockchain Trilemma but has contributed to it. Horizontal architecture has limited the decentralization, scalability, and security of blockchain infrastructure because when moving laterally in one direction, only a single block can form at a time, which results in more focused attack vectors, leads to slower and isolated block production, and compromises network security.

Moreover, the blockchain operates serially by design: each block references the previous one, and new blocks are added one at a time. Though certain processes, like transaction processing, can occur in parallel, the blockchain, by nature, creates a linear timeline for all data pushed to it. This can lead to slow transaction times and scalability issues when the number of transactions being processed increases. One of the biggest performance hits to existing blockchain systems is the conflict resolution required to decide which block should be next. This process for constant conflict resolution is embodied in consensus protocols such as proof-of-work and proof-of-stake.With blockchain technology, global stock market access has become easier for investors from various parts of the world. Geographical limitations and regulatory barriers can be

overcome, enabling cross-border investments more easily. The potential of blockchain in capital markets includes accelerating transactions on exchanges and reducing third-party involvement. Smart contracts offered by blockchain also facilitate various transaction activities in the financial sector.

Despite the growing interest in implementing blockchain technology, the results in real-world case applications vary, often resulting in failure or poor development, as shown in the examples of Maersk and Walmart. For example, Maersk had challenges securing complete cooperation from other corporations and governments for its blockchain technology initiative, leading to the project being discontinued in 2023. Walmart's blockchain technology initiative has faced delays due to the reluctance of agri-food suppliers to participate in the requisite digital record system. Walmart has supported its suppliers by offering technological education to further its blockchain technology initiative (Bousquette, 2022; Latan et al., 2024; Wardhani et al., 2022).

## Theoretical Framework

Understanding the Mechanisms of Blockchain Technology.Blockchain technology operates through the execution of transactions organized into groups known as blocks. Every block consists of a block header that includes the hash value of the preceding block, timestamp, nonce information, and the hash value of the Merkle tree. The Merkle tree contains all the current block's transaction records and recorded data. The blocks are then arranged in the chain according to the chronological order of the transactions while preserving the prior block's hash (Ibañez et al., 2023; Wardhani et al., 2022; Yu et al., 2018). This approach guarantees the prompt detection of any signs of tampering or fraud, maintaining transparency, security, and the irreversibility of the information on the network (Yermack, 2017).Investment is the placement of a certain amount of funds at this time with the hope of gaining profits in the future. Investing in the capital market requires sufficient understanding, expertise, and insight to determine which assets to purchase, divest, and retain in one's portfolio. Individuals aspiring to participate in the purchase and sale of stocks must relinquish the illogical practices associated with following trends, engaging in gambling, and similar behaviors (Sarumaha & Sugiyanto, 2023).

As an investor, you must be rational when dealing with the stock buying and selling market. Apart from that, investors must have a sharp estimate of the future of the company whose shares will be bought or sold. Investors who do not have the skills to do the above can contact securities dealers, brokers, or companies to ask for advice or opinions or entrust them to invest in mutual funds (Halim, 2005). The parties who carry out investment activities are called investors. Investors can generally be classified into two groups, namely individual investors (individual/retail investors), which consist of individuals who carry out investment activities, and institutional investors (institutional investors), which include insurance companies and depository institutions (banks and savings institutions), pension fund institutions, and investment companies. Investors also learn how to manage investor's wealth. Welfare in the context of investment means monetary welfare rather than spiritual welfare. Monetary welfare can be shown by the sum of current income and the present value of future income (Tandelilin, 2010). A financial instrument known as financial derivatives is also used in the capital market. These derivatives derive their value from the price fluctuations of an underlying asset (Boudreault & Renaud, 2019).

Investment management companies, financial institutions, and individual investors utilize derivatives to mitigate risks associated with fluctuations in stock and commodity prices, interest

rates, or foreign exchange rates. This is achieved without directly impacting the physical ownership of the underlying product. Derivative contracts are often used by individuals or organizations seeking to safeguard themselves against various business hazards (Farida, 2010). Many financial instruments can be categorized into this derivative group, including 1) Options, which are contracts in which one party agrees to pay a certain amount of compensation to the other party for the "right" (but not the obligation) to buy or sell something to the other party; 2) Forward contracts, which are contracts in which one party gets the right to buy something now at an agreed price but pays in the future; 3) Futures contracts, which are agreements or commitments between two parties to deliver or receive a financial instrument or commodity on a specific date in the future, at a price determined at the time of signing the contract; and 4) Swaps, which are transactions between two parties where the first party promises to pay the second party (Farida, 2010).

**Understanding Options**

An option is an agreement/contract between the option seller (seller or writer) and the option buyer (buyer) where the option seller guarantees the right (not obligation) of the option buyer to buy or sell specific shares at a predetermined time and price. The parties involved in options are investors and other investors and do not involve the company issuing the stock securities (issuer), which are used as an option. Investors issue options to sell to other investors. So, the company that is the issuer of the shares used as the benchmark has no interest in the option transaction. The relevant share issuer is not responsible for creating, terminating, or implementing the option contract. In practice, the types of securities that can be used as a benchmark for options are not only shares but can be in other forms, such as market indices (Tandelilin, 2010).

**Types of Options**

Based on the type of rights that occur, options can be grouped into two categories, namely:

**Buy option (call option)**

A call option is an option that gives the holder the right to buy a certain number of shares at a predetermined time and price. Investors who buy a call option hope that the stock price will rise and make a profit from the increase. By buying options, investors can speculate on increases in share prices without owning the shares and hope to profit from them. This means that if the expiration date arrives and the share price in the market rises above the price agreed upon in the option contract, investors who have a call option will be able to buy the shares at a lower price compared to the market price (Tandelilin, 2010). Four essential things need to be considered in a call option contract: the company whose shares will be purchased, the number of shares that can be purchased, the purchase price or exercise price of the shares, and the expiry date of the right to buy (maturity date). Systematically, the price of a call option is expressed using the following equation (Tandelilin, 2010).

$C = max\ (S_i - K, 0)$…… (1)

$S$i = Stock price at Time i

$K$ = Strike price

From the equation above, it can be concluded that the owner of the call option does not gain a profit if the strike price is greater than the share price at time i.

**Sell option (put option)**

A put option is the right to sell shares at a specific price within a specified time limit. The higher the agreed price, the greater the profit for us. If we have a put option, the more the stock price moves down continuously, the greater our profit. On the other hand, if stock prices increase for a long time, we could experience losses. The cost of a put option is systematically expressed using the following equation:

$P = max\ (K - S_i\ , 0)$…… (2)

$S$i = Stock price at Time i

$K$ = Strike price

From the equation above, it can be concluded that the put option owner does not make a profit if the share price at time i is greater than the strike price. Meanwhile, based on the execution time, the options are divided into two categories: 1) European options, which give the holder the right to exercise at maturity, and 2) American options, which give the holder the right to exercise at any time during the option period.

**Exotic Options**

An exotic option is an option whose payoff depends not only on the asset price at the time of executing the option but also on asset prices during the option period. Various types of options fall under the category of exotic options, such as barrier options, lookback options, Asian options, GAP options, exchange options, and compound options. Among these examples of exotic options, some are referred to as path-dependent options. Examples of path-dependent options include the carrier option and lookback option (Asian, 2013), and the focus of this research will be on Asian options.

**Asian option**

**Understanding Asian Options**

An Asian option is an option where the payoff is based on the average price of the underlying asset during the term of the option. Because the payoff of this option fluctuates less, this option gives the owner the right to buy shares at maturity at a predetermined exercise price (Hull & Basu, 2016). Asian options were first introduced by Boyle (1996) and Emmanuel (1980), were first used by Ingersoll, and were first traded in Asian markets only, especially in Tokyo (Hsu & Lyuu, 2011). There are several basic types of Asian options: 1) Average option deal and average option value, 2) Arithmetic mean and geometric mean, 3) Discrete model stock price average, and 4) American and European-type exercise times.

**Asian options payoff**

The average value of share prices determines the payoff of Asian options during the validity period of the option. There are two ways to determine the average value of share prices: the arithmetic and the geometric average. The average used in this research is the geometric average. Systematically, the geometric mean can be calculated using the following formula:

$(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}$ where $0 \leq t_1 < t_2 \ldots < t_n \leq T$ ……(3)

Based on the standard payoff for a call option in Equation (1) and the explanation above, a payoff

formula for discrete European-type Asian options can be formed using the geometric mean for discrete Asian options and the geometric mean for call options at maturity. That is:

$$payoff = \max\left(\prod_{i=0}^{n} S(t_i)^{\frac{1}{n+1}} - K, 0\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

S ($t_i$) = Stock price at Time i

$n$ = number of steps

K = Strike Price

**Stock price model**

When shares follow the Wiener process, ($t$) can be represented as an equation in the Ito process, resulting in the share price change model:

$S$ = Stock price

$r$ = risk-free interest rate

$\sigma$ = The distance between up/down fluctuations in a stock (Volatilities)

dW= Brown's motion follows the Wiener process

$t$ = Time of stock price movement

With $r$ (the risk-free interest rate) as the deterministic component, $\sigma$ (volatility) as the stochastic component, and $W$(t) as the Wiener process (Hastuti & Devianto, 2016).

**Multinomial Lattice Method**

The lattice method is one of the methods used to determine option prices. This method was popularized by Cox, Ross, and Rubinstein, who introduced the binomial tree in 1979. The lattice method is divided into the binomial method, where there are only two possibilities: the stock movement up and down, and the trinomial method, where there are three possibilities: the stock value movement up, the value movement fixed shares (not experiencing changes in value), and downward stock movements (Resnianty et al., 2016). The multinomial method is a development of the lattice binomial and trinomial methods. The multinomial lattice method has more nodes than the binomial and trinomial lattice methods. Therefore, this method produces higher accuracy values. In this method, each node has four branches, which replace two nodes for the connectivity underlying the lattice binomial method, and every five branches, which replace three nodes for the connectivity underlying the lattice trinomial method. The multinomial lattice method discussed in this research is a development of the binomial lattice method. Each node in the multinomial lattice method generally has I + 1 branches.

**Asian Options Using the Multinomial Lattice Method**

**Stock returns**

Stock returns are the results obtained from a stock investment in the form of profits, marked by a positive stock return value (capital gain), or losses, marked by a negative stock return value (capital loss). The equation for finding the stock return value is:

$$R_{(t)} = \frac{S_t - S_{(t-1)}}{S_{(t-1)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$R_{(t)}$ = Stock return

$S_{(t)}$ = Stock price in the current period

$S_{(t-1)}$ = Stock price in the previous period

**Variance Return**

Variance is a measure of the spread of data, which is used to determine how far the data is spread from its expected value. If the variance value is small, then the distribution of stock return data is close to the expected return. Conversely, if the variance value is large, then the spread of stock return data is away from the expected value. The equation for finding the variance value is as follows:

$$Var = \frac{\sum_{i=0}^{n}\left(R_{(t)}-\left(E\left(\bar{R}_{(t)}\right)\right)\right)^2}{n-1} \quad \text{……..……(7)}$$

When calculating the expected return (expected value), you can use the following equation:

$$E\left(R_{(t)}\right) = \frac{\sum_{i=0}^{n} R_{ti}}{n} \quad \text{…….....…… (8)}$$

$R_{(t)}$ = Stock return

n = Number of stock data

**Volatilities**

Volatility is the level of uncertainty that occurs in the stock market, which affects option prices. The volatility used in this research relies on historical volatility, which is calculated based on past data and is usually associated with the underlying asset. The equation to find the volatility value is as follows (Hull & Basu, 2016):

$$\sigma = \frac{1}{\sqrt{\tau}}\sqrt{Var} \quad \text{…….. (9)}$$

Where $\tau$ = 1/T, with $T$ being the number of active trading days in one year (252 days). So, the value of $\tau$ is 1/252.

**Parameters $u$, $d$, and $p$**

In the binomial model, if $S$t represents the stock at Time $t$, then $S$t has two possibilities: the stock can either rise to $Su$ or fall to $Sd$. Here, $u$ and $d$ are the factors that determine the stock going up or down, while $p$ represents the probability of the stock price rising by $p$ and the probability of it falling by 1- $p$. To determine the values of $u$, $d$, and $p$, we must combine various equations from the binomial model, as well as the parameter values of u, d, and $p$.

$$u = e^{\sigma\sqrt{\Delta t}}, \; d = e^{-\sigma\sqrt{\Delta t}} \text{ and } \; p = \frac{e^{r\Delta t}-d}{u-d} \quad \text{…….....….. (10)}$$

After that, the share price can be calculated to determine the point for $t$, namely:

$$S_{ji} = S_0 u^j d^{i-j} \quad \text{……..……(11)}$$

Where $S$ji indicates the share price at that time $t_1$, with an increase in share prices of $(i - j)$ times (for $i$ = 0, 1, ..., $N$ and $j$ = 0, 1, ..., $i$).

$$S_{00} = (S\ with\ \ j = 0, i = 0) = S_0 u^0 d^0 = S_0$$

$S_{01} = (S\ with\ j = 0, i = 1) = S_0 u^0 d^1 = S_0 d$

$S_{11} = (S\ with\ j = 1, i = 1) = S_0 u^1 d^0 = S_0 u$

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$S_{ij} = (S\ dengan\ j = j, i = i) = S_0 u^j d^{i-j}$

**Value Asian Options Using the Geometric Average**

The geometric mean is a type of average rarely used in financial practice, but it is commonly used to determine option prices in the case of Asian options. It is known that the share price equation:

$S(t_{i+1}) = S(t_i) \exp\left(\left(r - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t} Z_i\right)$ becomes

$$\ln\left(\frac{S(t_n)}{S(t_{n-1})}\right) = \left(r - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t} Z_i \quad \text{..... (12)}$$

$S_{(ti+1)}$ = Stock price at time ti+1

$S_{(ti)}$ = Stock price at Time ti

σ = Volatility of asset prices

Δt = $t_i{}_{+1}$ - $t_i$

Zi ~ NIID (0,1)

In Equation (4), it is known that the Asian option formula uses the geometric average, namely $(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}$ . Note that $\prod_{i=1}^{n} S(t_i)$ The product is the stock price at time ti, so we get. $\prod_{i=1}^{n} S(t_i) = S(t_n)S(t_{n-1}) \ldots S(t_2)S(t_1)$, using algebraic manipulation, the Equation it becomes:

$$ln\frac{\prod_{i=1}^{n} S(t_i)}{(S(t_0))^n} = \left(\left(r - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t} Z_{n-1}\right) + 2\left(\left(r - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t} Z_{n-2}\right) + \cdots + n\left(\left(r - \frac{1}{2}\sigma^2\right)\Delta t + \sigma\sqrt{\Delta t} Z_0\right) \quad \text{.....(13)}$$

The next step is to find the mean and variance for the distribution of the logarithm of the geometric mean. Here are the values:

Mean of the logarithm of the geometric mean

$$E\left[\ln\left(\frac{(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}}{S(t_0)}\right)\right] = E\left[\ln\left(\frac{\prod_{i=1}^{n} S(t_i)}{S(t_0)^n}\right)^{\frac{1}{n}}\right] = \frac{1}{n} E\left[ln\left(\frac{\prod_{i=1}^{n} S(t_i)}{S(t_0)^n}\right)\right]$$

Using Equation (13), the above expectation can be written as:

$$E\left[\ln\left(\frac{(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}}{S(t_0)}\right)\right] = \frac{(n+1)}{2n}\left(r - \frac{1}{2}\sigma^2\right)T \quad \text{..... (14)}$$

Variance of the logarithm of the geometric mean

$$Var\left[\ln\left(\frac{(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}}{S(t_0)}\right)\right] = Var\left[\ln\left(\frac{\prod_{i=1}^{n} S(t_i)}{S(t_0)^n}\right)^{\frac{1}{n}}\right] = \frac{1}{n^2} Var\left[ln\left(\frac{\prod_{i=1}^{n} S(t_i)}{S(t_0)^n}\right)\right]$$

By using Equation (13), the Variance above can be written as:

$$Var\left[\ln\left(\frac{(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}}{S(t_0)}\right)\right] = \frac{(n+1)(n+2)}{6n^2}\sigma^2 T \quad \text{..... (15)}$$

Based on the results in equations (14) and (15), it is obtained:

$$\left[\ln\left(\frac{(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}}{S(t_0)}\right)\right] \sim N\frac{(n+1)}{2n}\left(r - \frac{1}{2}\sigma^2\right)T, \frac{(n+1)(n+2)}{6n^2}\sigma^2 T$$ or it can also be written:

$$\left[\ln\left(\frac{(\prod_{i=1}^{n} S(t_i))^{\frac{1}{n}}}{S(t_0)}\right)\right] \sim N\left(\left(\hat{\mu} - \frac{1}{2}\,\hat{\sigma}^2\right)T, \hat{\sigma}^2 T\right) \quad \text{..... (16)}$$

Where,

S(0) = Stock Price at t = 0

T = Due date

n = The number of share prices calculated

$$\hat{\mu} = \frac{1}{2}\,\hat{\sigma}^2 + \left(r - \frac{1}{2}\sigma^2\right)\frac{n+1}{2n}$$

$$\hat{\sigma}^2 = \frac{(n+1)(n+2)}{6n^2}\sigma^2$$

Equation (16) shows that the logarithm of the geometric mean of stock prices is normally distributed. This implies that the geometric mean of stock prices follows a lognormal distribution. Since the geometric mean has a proven lognormal distribution, the Black-Scholes approach can be used to determine Asian option prices using the geometric mean. The Black-Scholes model is known for its high accuracy and can be considered an exact model. The Asian call option pricing model using the geometric average through the Black-Scholes approach can be expressed as follows:

$$C = (S(0)N[\hat{d}_1] - Ke^{-rT}N[\hat{d}_2] \quad \text{..... (17)}$$

Where:

$$\hat{d}_1 = \frac{\ln\left(\frac{S(0)}{K}\right) + \left(\hat{\mu} + \frac{1}{2}\hat{\sigma}^2\right)T}{\sigma\sqrt{T}}$$

$$\hat{d}_2 = \frac{\ln\left(\frac{S(0)}{K}\right) + \left(\hat{\mu} + \frac{1}{2}\hat{\sigma}^2\right)T}{\sigma\sqrt{T}} = \hat{d}_1 - \sigma\sqrt{T}$$

$$\hat{\mu} = \frac{1}{2}\,\hat{\sigma}^2 + \left(r - \frac{1}{2}\sigma^2\right)\frac{n+1}{2n}$$

$\hat{\sigma}^2 = \frac{(n+1)(n+2)}{6n^2}\sigma^2$

Where,

(0) = Current Stock Price

$K$ = Strike Price

$T$ = Maturity time

$r$ = Interest rate

$n$ = The number of share prices calculated

$\sigma$ = Volatility

$\hat{\mu}$ = Mean

$\hat{\sigma}^2$ = Variance

Asian option prices obtained using the multinomial lattice method may differ from those obtained using the Black-Scholes model. Hence, there is a disparity between the prices of the Asian option obtained using the multinomial lattice method and the Black-Scholes model. This difference is expressed as an error, and the formula for calculating the percentage error is as follows:

$$error = \left|\frac{Metode - Model\ Eksak}{Model\ Eksak}\right| \quad \ldots\ldots\ldots\ldots\ldots \quad (18)$$

**Calculating the value of the Asian call option at the current time**

A path has prices $S_0$, $S_1$, $S_2$, … , $S$n , where $0 \leq I \leq n$, has the sum of prices so far equal to:

$$P \equiv \begin{cases} S_0 \times S_1 \times S_2 \times \ldots \times S_{nI}, \ for\ standard\ Asian\ options \\ S_I \times S_{2I} \times \ldots \times S_{nI}, \ for\ forward - starting\ Asian\ options \end{cases}$$

P is the running time that corresponds to the average. Meanwhile, the condition at Time $n$ + 1 ($S_{n+1}$) is related to the current condition $n$ ($S_n$) and $P$. Then, this relationship is expressed through:

$$Q \equiv \begin{cases} P \times S_{I+1}\ , \ if\ n+1\ is\ monitor\ point \\ P, \ if\ n+1\ not\ monitor\ point \end{cases}$$

For the binomial model, when $n$ + 1 is the monitor point, then:

$$n, S_n, P_n = \begin{cases} n+1\ , S_n u, P_n + S_n u \quad to\ change\ up \\ n+1, S_n d, P_n + S_n d \quad to\ change\ down \end{cases}$$

Meanwhile, when $n$ + 1 is not a monitoring point, then:

$$n, S_n, P_n = \begin{cases} n+1\ , \ S_n u, P_n, \ to\ change\ up \\ n+1, S_n d, \ to\ change\ down \end{cases}$$

**Stock Markets & Stakeholders**

The stock market ecosystem involves various stakeholders – investors (retail and institutional), intermediaries (stock exchanges, brokers, clearing houses, and custodians), and other entities (issuers, market makers, and regulators). Some studies discussed the use of blockchain in stock

market transformation (Hull & Basu, 2016). There were considerations for a blockchain-based hybrid solution (Noble & Patil, 2021). It is a public ledger that openly shows all trades on the exchange (Miraz & Donald, 2018). Market players must carefully assess the consequences of adopting this technology as it evolves and work together towards its ethical and sustainable integration (Bhandarkar et al., 2019). Company-related studies show that investors find blockchain adoption a value-enhancing activity (Babu & Das, 2023), which motivates listed companies to embrace the technology. When the stock markets themselves begin implementing it, there is a high likelihood that the move will be well received. Blockchain reduces systemic risks and enhances investment efficiency (Jeong & Lim, 2023). Since institutional investors and financial institutions have an unfair advantage in terms of execution speed over smaller players due to factors like information asymmetry and access to better infrastructure, the centralized form of stock exchanges creates an uneven playing field (Chen et al., 2021). This issue can be addressed with the data highway protocol in blockchain, which is superior to the existing PoS and PoW mechanisms.

**Stock Exchanges**

Equities, Fixed Income, Derivatives, and Cash and equivalents. Traditional stock exchanges are indeed interested in using blockchain across all their segments. Major exchanges like NYSE and Deutsche Börse intend to use blockchain. In May 2015, NASDAQ launched Linq, the first blockchain-based trading application for private companies to represent their share ownership digitally, even though they are not listed on a stock exchange. The disruptive variant of blockchain is Decentralized Finance (DeFi). Decentralized Exchanges (DEX) allow customers to trade cryptocurrencies or digital currencies without a central authority or intermediary. However, they are designed more to deal with digital assets and not specifically traditional stocks. There are several challenging questions that one would encounter in the process of transforming conventional systems to blockchain-based systems. The migration is easier said than done, both because of physical implementations and economic reasons. Researchers argue that disintermediation is a goal of blockchain, but not all finance areas are ready for it or can implement it. Blockchain itself could become an intermediary offering trust in a decentralized way without disintermediation. So, traditional financial institutions will use blockchain based on their processes and products.

**Block chain**

Blockchain, most commonly known for its role in cryptocurrencies, offers a range of features that could significantly impact the energy sector. At its core, Blockchain is a decentralized, distributed ledger technology that ensures high levels of transparency, security, and efficiency in data management and transactions. In the context of the stock exchange, Blockchain has the potential to revolutionize how stocks are traded, distributed, and accounted for. The promise of Blockchain in the stock exchange sector lies in its ability to facilitate a more decentralized and democratized stock market. This could lead to the development of a peer-to-peer stock trading platform where consumers can buy, sell, or exchange directly with one another, bypassing the traditional market. Such a platform could increase the efficiency of stock trading and empower consumers to play a more active role in the trade market. Moreover, Blockchain's inherent characteristics of transparency and immutability make it an ideal solution for tracking stocks. This can lead to more accurate and reliable energy usage and generation data, which is crucial for managing stock resources and reducing stock footprints. Blockchain is a decentralized

technology that was developed to address the issues of security vulnerabilities and expensive administrative expenses associated with centralized systems. Participants collaboratively document and oversee transactions in a distributed network. Data is stored in blocks in distributed open-ledger blockchains that are built on peer-to-peer (P2P) technology. Every block is interconnected and stored in a sequential manner using hash values. Blocks are partitioned into two components: block headers and block bodies. Block headers include many vital components, including the version, Merkle root, block creation time, mining difficulty, and previous block hash value. Every block is linked to the preceding one (Cai, 2018; Heo et al., 2021).

**Blockchain Technology Basics**

To understand how blockchain technology can revolutionize the stock trading sector, it is essential to grasp how blockchain functions. At its core, blockchain technology is a type of distributed ledger technology (DLT) that allows data to be stored globally on thousands of servers while enabling anyone on the network to see everyone else's entries in near real-time. This makes hacking transparent and challenging, as each 'block' of data is linked to the previous one, forming a secure and unalterable chain.

**Explanation of Blockchain**

**Structure**: A blockchain is a series of immutable records called blocks, linked and secured using cryptography. Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data.

**Decentralization**: Unlike traditional databases managed by a central authority, the blockchain is decentralized and managed by a peer-to-peer network collectively adhering to a protocol for validating new blocks.

**Consensus mechanism**: The blockchain employs consensus mechanisms like Proof of Work (PoW) or Proof of Stake (PoS) to agree on the validity of transactions. This ensures that each transaction is confirmed and recorded without a central authority.

The blockchain works by recording transactions.When a transaction occurs, it is broadcasted to a network of computers, known as nodes, for verification and validation. Nodes validate the transaction using established algorithms and add it to their blockchain copy, forming a new block. Once verified, the transaction is combined with others to create a new block of data for the ledger, linking it to the existing blockchain. The new block is then added to the existing blockchain in a permanent and unalterable way.

**Blockchain Consensus Algorithms**

Blockchain is a decentralized technology that links several nodes in a peer-to-peer network to authenticate and record transaction data. There may inevitably be delays and failures in delivering information in P2P networks. Hence, even in the absence of deliberate data falsification, there exists a potential for redundant processing resulting from double transmission and malfunction arising from inaccurate information. We provide a consensus method as a solution to address these issues (Heo et al., 2021; Rouhani & Deters, 2019).Proof of work (PoW) is a consensus technique often used in public blockchains, most notably in the context of Bitcoin. The individual who successfully resolves a particular issue using computer computing is given the privilege to generate a block (Heo et al., 2021; Wang et al., 2019).Nevertheless, Proof of

Work (PoW) relies on the amount of energy expended and the successful resolution of the issue, making it potentially wasteful in some circumstances.In addition, we evaluated the proof of stake (PoS) consensus method, which allocates block creation authority based on the stake amount rather than computational power. This approach effectively mitigates the wastage of computational and electrical resources (Heo et al., 2021; Nakamoto, 2008).

## Research Methodology

This study is a documentary. The research population comprises previous publications that address comparable blockchain and stock market subjects. Subsequently, the author arranges and compiles a written synopsis of the acquired results (Puthal et al., 2018; Wardhani et al., 2022).The written summary is then subjected to descriptive analysis, wherein the author's interpretation of the findings is utilized to gain comprehension and provide explanations. This approach yields multiple advantages in applying blockchain technology, particularly in enhancing pricing calculations for European-type Asian options through the utilization of the multinomial lattice method on the blockchain. Integrating the multinomial lattice concept with blockchain technology can enhance transparency and security in determining share prices. Additionally, we can bolster network security and improve the quality of corporate governance by establishing transparency, accountability, and high levels of trust among all participants in blockchain technology networks. The issuers will be classified based on the aims of this research (Creswell & Poth, 2016; Wardhani et al., 2022).

The research question of this study is, "Can blockchain be used in traditional stock markets with the Multinomial Lattice method to determine stock option prices?". As a result of the research question, the research objective can be formulated as follows: "To envision potential scenarios and use cases where blockchain can be used in traditional stock markets without disrupting them". Since the research problem is new and only a meager amount of information is available, this research intends to use an exploratory research methodology to understand the concepts and move toward a potential solution. As part of this, the researcher discussed the research problem with members working in various roles in the stock market. Later, a literature review is done to understand, identify, and find if blockchain has a use case that can address the situation. Blockchain transformations require wide-ranging industry cooperation and should be slowly introduced. Blockchain use for traditional markets without disrupting intermediaries is less explored, and hence, this research wishes to address a gap in concepts and perspectives.

## Result and Discussion

### Multinomial Lattice Method Implementation

We used 252 Apple Corporation (AAPL INC) share price data over one year to determine option prices. The data used are daily closing stock call option price data, calculated using the Lattice multinomial method and MATLAB 7.6.0 software.

**Table 1. Asian-type stock call option prices (geometric mean)**

| | Asian-type stock call option prices | |
|---|---|---|
| **n** | **Multinomial Lattice** | **Black-Scholes** |
| 2 | $55,5602 | $56,6726 |

| | | |
|---|---|---|
| 3 | $55,9993 | $56,4678 |
| 4 | $56,3300 | $56,3729 |
| 5 | $56,5985 | $56,3184 |
| 6 | $56,8269 | $56,2460 |

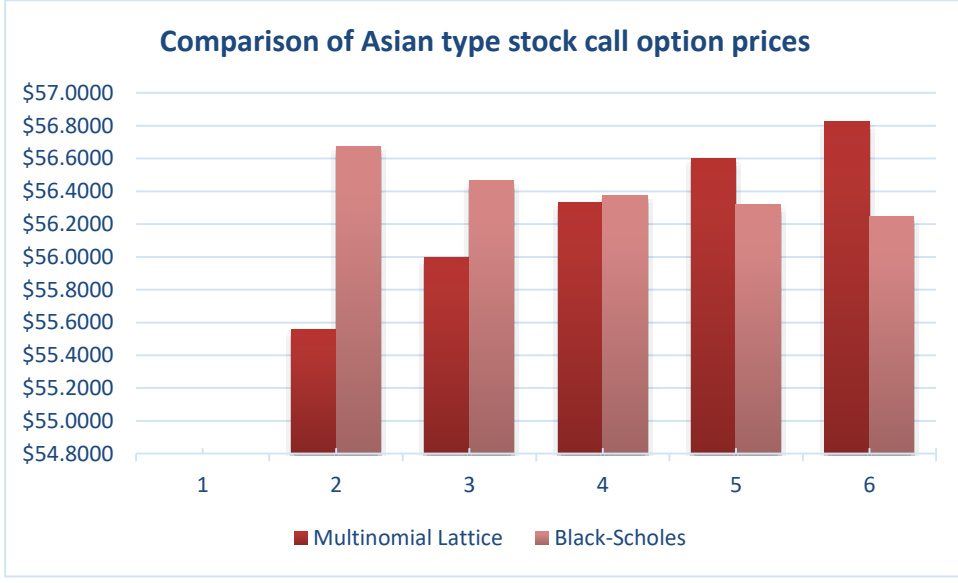


**Figure 1.** Comparison between Multinomial Lattice and Black-Scholes

The error of the multinomial lattice method can be calculated using Equation (18). Based on the price of the Asian-type stock call option in Table 1, the error is calculated as follows:

**Table 2. Error**

| n | Error |
|---|---|
| 2 | 0.0196 |
| 3 | 0.0083 |
| 4 | 0.0008 |
| 5 | 0.0050 |
| 6 | 0.0103 |

Below is a multinomial tree of stock price movements (*S*ji) for three periods, starting from the initial stock price and ending with the period stock price, with an interval (n) = 3.

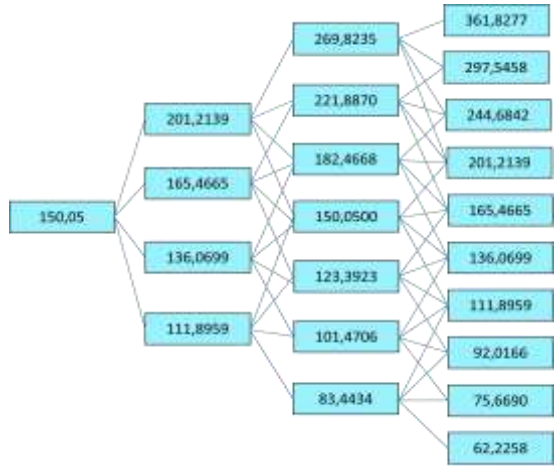


**Figure 2.** Multinomial tree diagram of stock price movements

The multinomial tree scheme for Asian-type stock call options, which is a transformed form of a binomial tree, is shown in Figure 3 below.

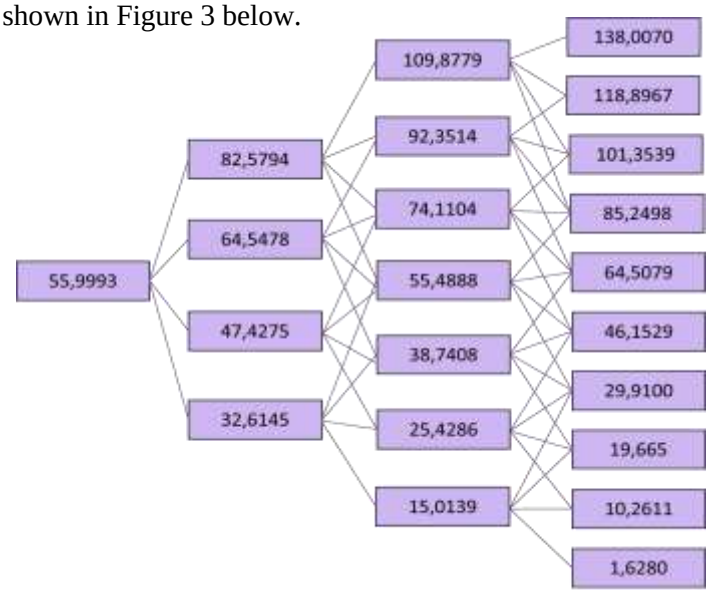


**Figure 3.** Call option prices (C) with interval n = 3

## Framework Blockchain Technology

Blockchain technology falls under the broad umbrella of technologies called Distributed Ledger Technologies (DLT). Blockchain is a distributed, decentralized, public ledger across a network. It is designed to achieve decentralized security and trust in several ways, including its key concepts of decentralization, immutability, and transparency. The fundamental principles of blockchain technology involve Blocks, Chains, Consensus mechanisms, Decentralization, and Immutability.

Potential applications of Blockchain in the stock markets: Blockchain technology can be used in stock markets to reduce costs, improve efficiency, and increase transparency. It can enhance the

stock market infrastructure, efficiency, transparency, and security, such as clearing and settlement processes, trade reconciliation, and trade lifecycle management. When Blockchain is used in minimal or no disruption applications, the decentralization feature is the best to be sacrificed, thereby giving higher importance to security and scalability. This classic trade-off is the Project Management Triangle (Habsy, 2017) or the Blockchain Trilemma, in which the implementer has to sacrifice one of the three options between decentralization, security, and scalability to embrace the other two options.

A private Blockchain system can be created by the stock exchange that intends to implement the system. Being a permissioned Blockchain, only authorized members can access it. Private blockchains can be used to maintain the privacy of transactions, thereby benefiting from blockchain technology features. Smart contracts can be programmed to execute trades automatically when certain conditions are met, such as the price of a stock reaching a certain level.

Some early research pointed out that the design and weakness of Blockchain make it unsuitable for use by stock markets (Port, 2022). However, several developments have happened since then. Blockchain is now said to be in its fourth generation. The first-generation Blockchain was designed to improve financial systems by offering a decentralized monetary platform that puts the control of money in the hands of the users. The second-generation Blockchain, represented by Ethereum, introduced the concept of smart contracts. Smart contracts are self-executing contracts with the terms of the agreement between the buyer and seller being directly written into lines of code. The third-generation Blockchain focuses on the scalability and interoperability issues of previous generations. The fourth generation of blockchain technology aims to make it more suitable for business environments, creating and running more improved and mainstream decentralized applications using innovative features like Web 3.0, Metaverse, and Secure self-recording applications.

**System Architecture Blockchain-Based Stock Exchange**

This section describes our system's architecture, which is a decentralized stock exchange platform based on a consortium blockchain among financial and organizational entities that are already part of the traditional stock market. First, we provide an overview of the system's architecture. Then, we define the roles and responsibilities of the participating entities. Finally, we present the smart contract that holds and manages the stock exchange trading logic. Please refer to Figure 4.

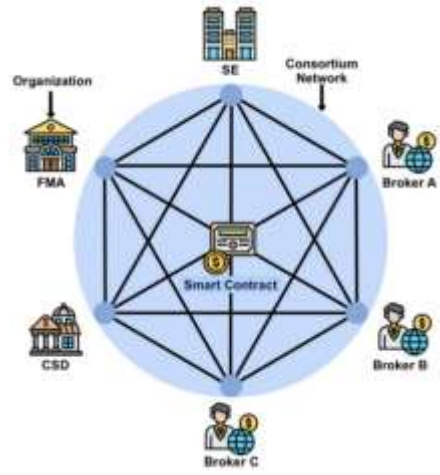


**Figure 3.** System architecture Blockchain(Source:(Al-Shaibani et al., 2020)).

One benefit of using blockchain technology is that it facilitates direct investment cash flow in stock trading, bypassing the need for a broker and allowing money to travel directly to the issuing firm. Hence, blockchain technology can eliminate the need for intermediaries in stock trading, resulting in faster and real-time transaction completion. It also eradicates the potential for intermediaries to misuse funds and simplifies the investment chain, as depicted in Figure 5 (Wardhani et al., 2022).

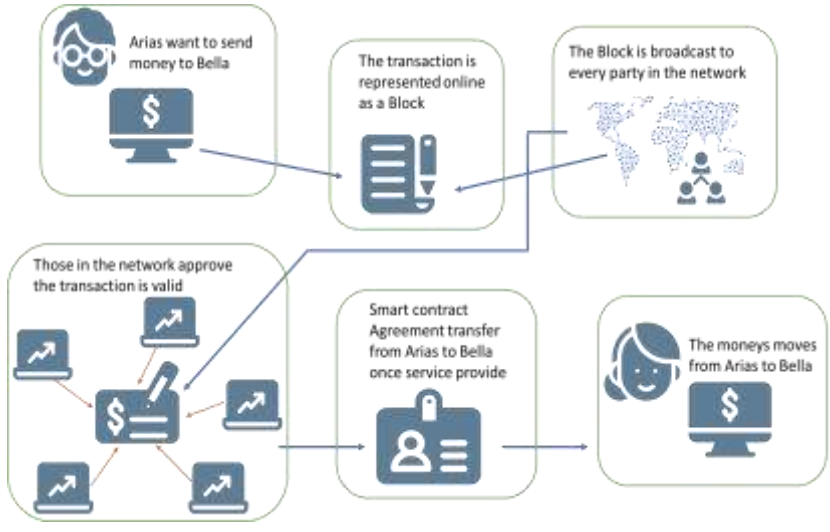


**Figure 4.** Flow of Funds Blockchain Technology (Source: Author Compilation)

Stock trading can be conducted directly on a stock market using blockchain technology without the need for an intermediary or broker. Trading transactions occur solely between investors and the issuing corporation, with cash being immediately sent to the issuer. This allows for faster transaction speeds, even in real time (Wardhani et al., 2022). Investors can greatly benefit from the increased transaction speed and the elimination of intermediaries, as it reduces expenses associated with share ownership, such as brokerage fees. This enables them to optimize the use

of their assets for stock investments or other purposes (Kokina et al., 2017; Wardhani et al., 2022; Yermack, 2017).The use of blockchain technology in stock trading will enhance liquidity and increase the frequency of stock trading.

## Conclusion

"Can blockchain be used in traditional stock markets with the Multinomial Lattice method to determine stock option prices?" As a result of the research question, the research objective can be formulated as follows: "To envision potential scenarios and use cases where blockchain can be used in traditional stock markets without disrupting them. Moreover, by utilizing the multinomial lattice method, we can calculate the prices of European-type Asian options on the blockchain. By combining the multinomial lattice concept and blockchain technology, we can achieve better transparency and security in determining share prices and improve network security and corporate governance quality. This is due to transparency, accountability, and high trust between all parties involved in the blockchain technology network.

Blockchain transformations require wide-ranging industry cooperation and should be slowly introduced. Blockchain use for traditional markets without disrupting intermediaries is less explored. Hence, this research aims to address a gap in concepts and perspectives.

While disruptive features suggest a whole new way of adoption for the stock markets, blockchain has applications that can transform the traditional stock markets. Eliminating intermediaries is complex and cannot be taken up immediately. Hence, a gradual transformational approach is suggested to improve adoption. Various stakeholders of the stock market ecosystem can consider adopting the technology and benefit from its advantages, such as faster settlement, guaranteed settlement, and reduced cost. Compliance processes can be automated. Blockchain will have to face stringent regulatory and legal hurdles as it becomes a critical infrastructure of the economy.

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**Author Contribution**

Salman Farizy,S.Kom.,M.Kom: Conception and design of study.

Drs.Afrizal Zein, M.Kom: Acquisition of data.

Ghema Nusa Persada,S.Kom.,M.Kom: Analysis and/or interpretation of data.

Endin Fahrudin,S.T.,M.Kom: Drafting the manuscript.

Dra.Dwi Liestyowati, M.M.,M.T: Revising the manuscript critically for important intellectual content.

Andiyan,S.T, M.T: Approval of the version of the manuscript to be published.

**Conflict of Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data Availability Statement**

The data supporting the findings of this study are available upon request from the corresponding author. Due to the nature of this research, participants were not asked for permission to share their data publicly, so supporting data is not available.

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